

ASSESSING THE CASE FOR REQUIRING AEB ON CITY BUSES AND DEVELOPING TECHNICAL REQUIREMENTS AND TEST PROCEDURES

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ABSTRACT

In London, around two-thirds of those killed in collisions involving a bus are pedestrians and most of these are killed crossing the road. The time between the pedestrian first being recognisable as a threat and the moment of impact is usually less than 2 seconds. Human drivers have very limited opportunity to avoid the collision. Automated Emergency Braking (AEB) has been developed to avoid such collisions and is becoming widespread on passenger cars. However, city buses pose a unique additional challenge. Bus operations already generate a significant quantity of non-collision injuries because passengers fall during normal operation. This includes when standing, or seated but unrestrained, passengers fall under braking. Automated brake applications where deceleration exceeds what a human driver would have applied increases this existing injury risk.

The research was sponsored by Transport for London (TfL) and aimed to quantify this balance of opportunity versus risk, and generate technical requirements allowing them to encourage or mandate AEB on their London bus fleet. The work involved:

- Traditional collision data analysis
- Case by case review of both collision and non-collision incidents recorded by CCTV systems provided by a London bus operator
- A road trial involving an AEB-equipped bus
- AEB Performance tests on a closed test track.

Up to around 25% of bus-pedestrian fatalities could be prevented. In true positive situations, any additional risk to bus occupants was small. Human drivers rarely failed to brake in collisions with pedestrians, they just braked too late to avoid collision. Earlier intervention would mean that in some cases AEB could achieve avoidance with lower deceleration than the driver actually applied. In others, only a small increase was required.

False positives always create additional risks. The extent of the risk was strongly related to the level of deceleration and increased very substantially at 6 m/s² or above in the modelling. The net balance was a likely increase in slightly injured casualties but a substantial decrease in deaths and serious injuries.

Technical requirements were developed based on adaptations of the Euro NCAP standards with two false positive tests added to discourage systems that were inadequately tuned.

The analysis is strongly dependent on the rate of brake applications in service at different deceleration levels, the number of bus occupant injuries that occur at those levels and the decelerations achieved during an AEB false positive event, which is often of very short duration. Larger scale in-service trials would help to quantify these parameters more robustly.

Despite some risks, overall AEB would have strong safety potential on city buses and can be encouraged through TfL's bus safety standard in co-operation with manufacturers and researchers to mitigate risks as far as possible.

INTRODUCTION

In London, around two-thirds of those killed in collisions involving a bus are pedestrians and most of these are killed crossing the road. In these fatal cases, the time between the pedestrian first being recognisable as a threat and the moment of impact is usually less than 2 seconds. Human drivers have very limited opportunity to avoid the collision.

Advanced Emergency Braking (AEB) is a system that uses forward looking sensors such as Lidar, Radar, Camera, or combinations of more than one sensor, to identify a risk of an imminent collision. It will typically first warn the driver of the risk and, if the driver does not act, then it will apply braking automatically to avoid the collision or to reduce the collision speed and therefore the potential for injury.

AEB systems have been developed to avoid certain types of car, pedestrian and cyclist collisions and is becoming widespread on passenger cars. However, city buses pose a unique additional challenge. Bus operations already generate a significant quantity of non-collision injuries because passengers fall or sway during normal operation. This includes when standing, or seated but unrestrained, passengers fall under heavy braking. Automated brake applications where deceleration exceeds what a human driver would have applied will, therefore, create additional injury risk.

The research was sponsored by Transport for London (TfL) and aimed to quantify this balance of opportunity for the prevention of serious injury, particularly to pedestrians, versus the risk of an increased incidence of falls among bus occupants. The research was also intended to develop technical requirements allowing TfL to specify the fitment of appropriate AEB on their London bus fleet.

DATA SOURCES

Collision Data Analysis

A sample of 48 police fatal collision reports where London buses were involved, previously compiled by (Edwards, et al., 2017), were analysed to provide detailed information about the circumstances of fatalities arising from collisions with a bus.

Additionally, Transport for London's Incident Reporting and Investigation System (IRIS) database was analysed to identify collision incidents, in which someone on board the bus had been injured, and non-collision incidents where injuries had been caused by a slip, trip or fall during normal operation.

These data were supplemented by a sample of mainly lower severity incidents obtained from a review of the CCTV incident records of one bus operator. The CCTV footage included an overlay of some telematics data allowing the timing and magnitude of any driver or passenger actions to be identified (e.g. brake pedal application and x/y acceleration). The ability of the CCTV data to define the moment the pedestrian became recognisable as a threat, the moment the driver braked, and the amount of braking applied, was a major advantage over many other studies that have relied only on approximations and judgement from traditional collision reconstruction.

Track Tests

Two sets of track tests were completed. Firstly, the authors were not aware of any production AEB system fitted to a city bus and only one production AEB system fitted to an HGV that was sensitive to collisions involving pedestrians. It was known from the development of pedestrian AEB for passenger cars that the ability to apply the brakes hard and quickly was important to the potential casualty savings. It is well documented that commercial vehicle air brakes combined with commercial tyres could lead to slower brake build up times and lower peak acceleration potential than for passenger cars. Given this lack of existing information about the likely performance of AEB fitted to buses, independent testing of a system was considered necessary to establish the potential. At the time, Alexander Dennis buses was part-way through the development of an AEB system sensitive to front to rear, pedestrian and cyclists and agreed to provide a prototype vehicle for the test work and to provide technical support, allowing the project team some insight into the details of what the sensor system saw and reacted to.

The Euro NCAP AEB VRU 2018 protocol was selected as the basis for the evaluation testing because it provided the greatest coverage of the relevant test conditions required for a city bus, e.g. pedestrian and cyclist manoeuvres.

Later in the project additional track tests were also undertaken to evaluate two false positive scenarios that were under consideration for inclusion in the final technical requirements based on the false positive scenarios identified during the road trial, and to validate the test protocol defined for true positive testing.

Road Trial

The main objective of the road trial was to characterise the type of false activations that occur during normal driving to support the development of suitable false positive tests within the technical requirements. It should be noted that the prototype system had not, at that stage of development, undergone any tuning to eliminate false positives. It was, therefore, expected that substantial numbers of false positives would occur, and the system cannot be considered representative of what is expected of the fully developed system. However, it could be considered representative of an under-developed system that any technical specification should aim to prevent entering service. A secondary objective was to gather data on the frequency and magnitude of typical brake activations during normal service.

A single decker bus of similar type and construction to that which is typically used in London was used for the road trial. The vehicle was equipped with the prototype AEB system that was set-up to operate in an open loop or “Shadow Mode” – whereby it was actively monitoring the road environment, processing data and making decisions on warning and brake action, but the output signals were not connected to the normal bus controls so that no automated braking could take place. Thus, the control of the vehicle remained fully with the driver. The manufacturer recorded data from the AEB sensors/systems and, within commercial constraints, non-sensitive data was shared with the project team. In addition to this, independent data was recorded and overlaid onto a video that was synchronised to four cameras, as shown in Figure 1, below.

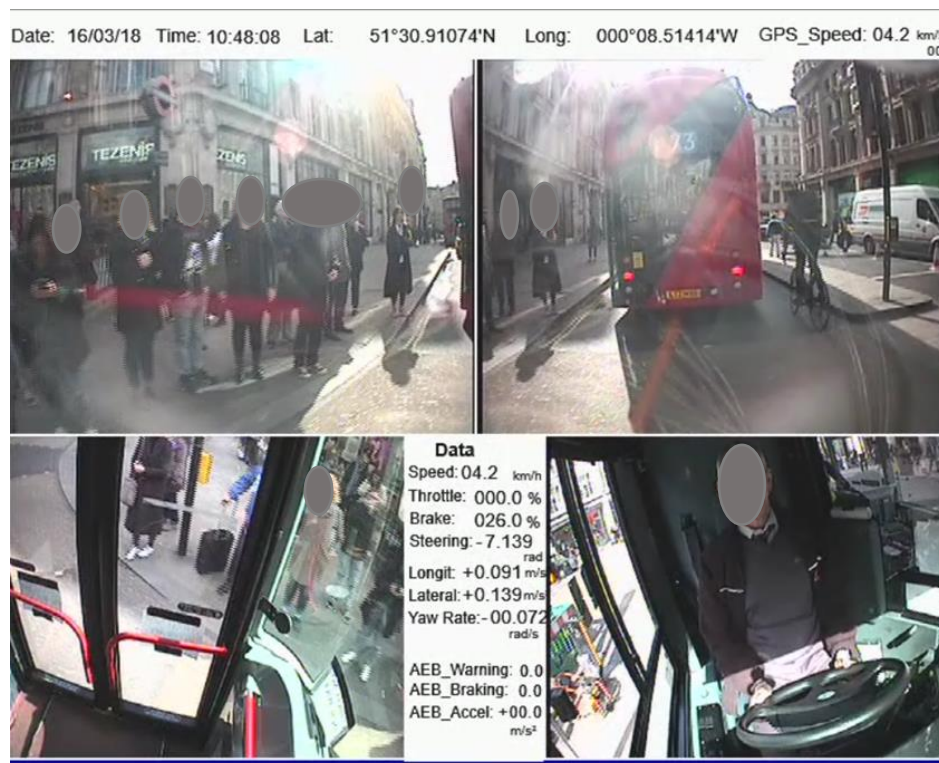


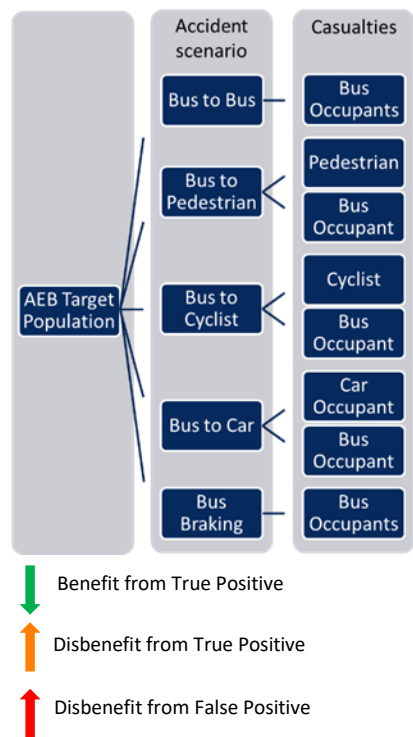
Figure 1: Example of video and data collection during the road trial

Although the bus was not in service during the trial, official London bus routes were followed, driven by drivers from the bus companies operating those routes and familiar with them, and the drivers were instructed to pull into bus stops and bring the vehicle to a stop as they would under normal operation.

Six different drivers drove the vehicle a total of 399km during a one-week road trial, covering five different routes. The routes selected included the wide range of bus driving environments likely to be encountered in service in London, while still being broadly representative of the most common routes and situations. They had been chosen partly based on including routes with both high and low casualty rates per km, as well as practical constraints in terms of ensuring support from the operators of those routes.

METHODOLOGY

The analysis was structured to consider the effects of true positive and false positive activations, as illustrated by Figure 2. For True Positive scenarios, AEB could potentially activate in different types of collision; offering a



casualty saving by avoiding or mitigating the severity of a collision but also potentially risking an increase in the frequency or severity of injury to bus occupants due to falls. The STATS19 database, the bus fatal database and CCTV footage from a bus operator were used alongside data compiled within the system verification and road trial parts of this project to estimate the likely effects on casualty numbers as a result of fitting AEB.

False Positive incidents represent cases in which the AEB system activates when it should not have done so. The effect of such incidents was estimated by analysing the typical bus occupant injury outcome of non-collision incidents caused by vehicle braking (road trial, IRIS data and operator CCTV data) and the magnitude of acceleration applied in false positive activations (road and track trials).

The true positive benefit of the system was evaluated on a case by case basis across the samples of police fatal and operator CCTV data available, using reconstruction, calculations and engineering judgments to assess whether the system was likely to have avoided the collision or reduced the impact speed. It was assumed that the above samples were broadly representative of Britain's official Road Accident Statistics (STATS19) data set within the Greater London Area. Therefore, the estimated effect identified in those samples was applied to a similar data set from STATS19 to estimate the casualty savings that could be expected within London each year.

Figure 2: True positive and false positive analysis

True Positive Analysis

For car occupant, pedestrian and cyclist casualties completely avoiding the accident or reducing the impact speed was expected to reduce the number and/or severity of casualties since the magnitude of deceleration experienced during the impact was likely to be greater than that experienced during braking. For bus occupants injured in collision with cars and other vehicles then collision avoidance or a reduction in collision speed would also be expected to substantially reduce the acceleration they experience and, hence, the probabilities of falls or other injuries which may otherwise be likely because of the fact they are standing or seated but unrestrained. However, when a bus hits a pedestrian or cyclist, the acceleration caused to the bus by the impact is negligible. So, the benefit to the bus occupant of avoiding or mitigating the collision is also negligible. An AEB system can brake no harder than the best human driver, so in the best case, there is no difference to the level of risk from braking. However, it is well documented, for example (Perron, et al., 2001) (Dodd & Knight, 2007) that many human drivers do not fully exploit the maximum braking performance available to them and may brake less sharply than the best human driver. Therefore, in some circumstances, an AEB system could brake harder than the average human driver which could increase the frequency or severity of injuries on board the bus.

Of course, emergency braking does take place in bus to pedestrian collisions where AEB is not fitted. Thus, the number of bus occupants injured in single vehicle collisions with pedestrians was taken as a baseline. Data on the

distribution of on-board injuries in relation to peak deceleration, taken from the study of bus operator CCTV incident records, was combined with data on the average occupancy of buses to estimate how this baseline number might change if AEB were fitted to all vehicles.

False Positive Analysis

In a genuinely false positive situation, automated braking always creates a risk of injury to bus occupants that would not have existed if AEB was not fitted. However, it is worth noting that, true and false positives are not as binary as the name implies. There are many situations where whether an activation should be considered false is open to significant interpretation and several studies have considered additional categories of ‘premature’ positive, near miss, or even desirable false positive, e.g. Lubbe (2014). These are activations that occur where there is a clearly recognisable hazard that prompts the activation but where the activation occurs at a time where the driver considers themselves aware of the risk and able to avoid it themselves without assistance. In addition to this, a false positive does not necessarily mean the brakes are applied until the vehicle comes to a complete stop. The sensing, detection and decision system may ‘make a mistake’ and activate the brakes but may also ‘realise it’s error’ only a short time later and subsequently release the brakes. Thus, false positives could potentially be of much shorter duration than true positives (i.e. a lower change in velocity).

At the time of the project no published information was identified to confirm the typical false positive rate experienced by comparable AEB systems in production, the proportion of those that were completely false or just premature, or the proportion that were momentary blips of the brakes compared to full emergency stops.

RESULTS

The two main questions that this research was aiming to answer were:

1. Does the fitment of AEB on buses produce a net safety benefit?
2. If so, develop a test procedure and rating system that can be used to encourage the most effective systems

Does the fitment of AEB on buses produce a net safety benefit?

True Positive Collision Situations. Collision data for London shows that in terms of fatalities from collisions with buses, by far the largest group is pedestrians. AEB was expected to be of benefit where the bus was travelling at normal traffic speeds and the pedestrian crossed the road in front of them or was walking along the road in the same direction as the bus. AEB was not expected to be of benefit where the bus was turning into or out of a side road at the time of collision or where the vehicle was just moving off from rest. A total of 21 relevant fatalities (with sufficient information for the reconstruction) were identified in the Police data and a total of 27 relevant non-fatal casualties were identified in the operator CCTV data. All cases in the sample were crossing scenarios.

For the fatalities, the travel speeds of the buses involved was between 5 and 36 mile/h with an average of 20 mile/h. This is likely to reflect the prevailing speed limits and traffic collisions typically resulting in low travel speeds in London. It was found that in all cases, there was less than 2 seconds available between the pedestrian becoming recognisable as a collision threat and the moment of impact, with an average time of just 0.76 seconds. Given typical human reaction times of between 0.75 and 1.5 seconds, e.g. (Olson & Farber, 2003), then avoiding collisions would be very challenging for human drivers. The study found evidence to show that 45% of the drivers involved did manage to react before impact but even in these cases the action was insufficient to avoid collision and the average impact speed was in fact only 1 mile/h less than the average travel speed before reaction.

For the non-fatal casualties, identified in the operator CCTV data, the bus travel speeds were very similar, ranging from 11 to 30 mile/h with an average of 17 mile/h. However, in these cases, the time between the pedestrian first becoming recognisable as a possible collision threat and the moment of impact tended to be greater, with a range from 0.7 seconds to 4.1 seconds, and an average of 2 seconds (1.24s longer than in the fatal cases). This translated to a higher proportion of drivers reacting before collision (87%) and a greater reduction in speed at the moment of impact, with impact speeds ranging from 7 to 15 mile/h, with an average of 11 mile/h (8 mile/h less than the average in the fatal cases). In the CCTV data it was also possible to calculate the amount of time that passed between the

pedestrian first becoming recognisable as a collision threat and the moment the driver first took avoiding action. This was found to range between 0.7s and 3.9 seconds, with an average reaction time of 1.9 seconds, slower than might be expected based on the body of laboratory and test evidence, e.g. (Olson & Farber, 2003) (Coley, et al., 2008), typically used in collision reconstruction. However, the case involving the 3.9 seconds was a bit of an outlier in an unusual case where the moment the pedestrian became a threat was open to interpretation. Ignoring this case changes the reaction times to between 0.7 and 2.5 seconds with an average of 1.7.

The peak accelerations achieved during braking were available and ranged between -1.4 m/s^2 -8.7 m/s^2 , with an average of 4.3 m/s^2 . Mean accelerations over the course of the stop were considerably lower with an average of 2.9 m/s^2 . This is likely to reflect the well documented fact (Perron, et al., 2001) (Dodd & Knight, 2007) that drivers often do not exploit the maximum braking available to them. Some stakeholders have suggested this may be exacerbated for bus drivers by the training they are given to brake gently during normal driving to help prevent passenger falls.

In each case, the potential benefit of AEB was assessed by replacing the actual driver reaction, with an AEB reaction. The AEB applied braking was assumed to commence at the lesser of the time to collision (TTC) at which the pedestrian became recognisable as a threat minus a system reaction time, or a range of TTC at which the AEB in the prototype bus actually commenced braking in the true positive track tests. The acceleration applied was the lower of the level required to avoid impact or the maximum that the system could achieve. A new impact speed was then calculated based on the initial travel speed, the moment of AEB activation and the level of deceleration applied.

The maximum deceleration that could be applied by an AEB system on a bus was initially based on the levels observed in track tests of the prototype system. However, the debate between maximising protection to collision partners and minimising risks to bus occupants meant that it was conceivable maximum deceleration should be capped. Thus, three ‘nominal’ systems were defined based on maximising deceleration (9 m/s^2 peak) or capping peak deceleration at either 7 or 5 m/s^2 .

Across all the variations, it was found that between 10% and 48% of the fatal sample and between 48% to 89% of the non-fatal sample could potentially have been avoided by fitting AEB. In addition to this, the results suggested that 14% to 43% of the fatal sample could have had at least some mitigation of impact speed and 4% to 41% of the non-fatal sample. It should be noted that the uncertainty in some parameters meant that ranges were used and thus there is overlap in the populations for avoidance and mitigation. That is, where a case would definitely have been avoided it will not appear in the mitigation figures. Where a case definitely cannot be avoided it may appear in neither figure or the mitigation only. Where there is some chance of avoidance but, if not avoided, a better chance of mitigation, then it appears in both sets of figures.

It was found that a large proportion of the benefits obtained above, were obtained due to an earlier braking intervention than provided by the driver. However, it was also found that on average, the AEB would have applied greater deceleration than the population of real drivers did, even though in some individual cases the AEB had to apply less deceleration to avoid the collision than the driver eventually applied later in failing to avoid collision. On average, the AEB systems increased the mean braking deceleration from 2.9 m/s^2 to between 3.0 and 5.5 m/s^2 , depending on the system characteristics assumed.

Analysis of the CCTV data highlighted that for different ranges of peak deceleration, the proportion of passengers that sustained slight or moderate injuries increased with increasing deceleration (Figure 3). The difference between the proportion of occupants injured from AEB braking to the proportion of occupants injured during driver-applied deceleration represents an additional risk to bus occupants. By applying the change in acceleration from driver-controlled to AEB-controlled to all bus occupants on board at the time of the pedestrian incidents, the total number of bus occupant injuries was estimated. It was assumed that all buses involved in collisions with pedestrians had the average number of passengers on board (19.3)¹.

¹ Source: DfT Bus Statistics Table BUS0304 data for London in 2016/17. Note that the equivalent figure for England excluding London is 9.5 suggesting any risk to occupants would be substantially lower outside of London

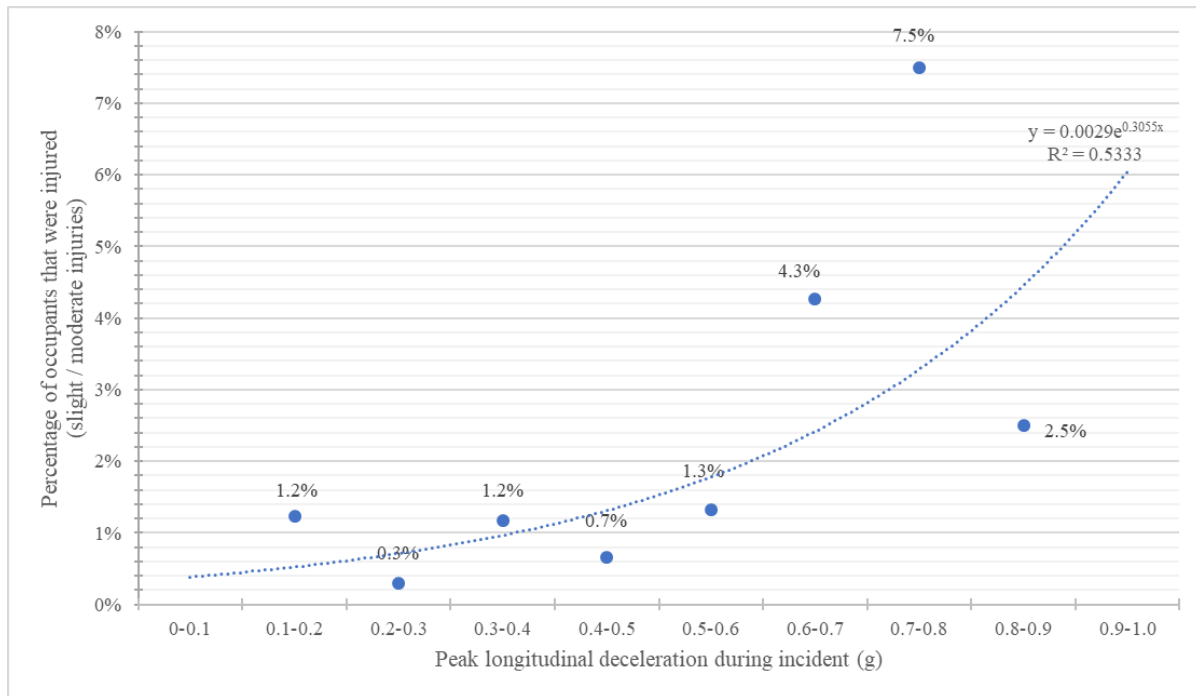


Figure 3: Proportion of occupants on board the bus that were injured during braking events, by magnitude of peak deceleration. Source: Sample of operator CCTV collision records.

This form of analysis was repeated for collisions with cars, other buses, and cyclists. The percentage effectiveness figures were combined with total casualty populations derived from the UK national accident database (STATS19) restricted to London only and the total net casualty effects in true positive situations was calculated.

False Positive Situations. If the AEB system were to apply braking in a situation where most careful competent and alert human drivers would not have applied braking, it can be considered a false positive. In this situation, the braking creates a risk of injury to bus occupants, and potentially other road users though they should still be travelling at a distance to be able to avoid collision with the braking bus. A subtle but important distinction is that this is different from a situation where the system applies braking in response to a recognisable threat of collision but that this is applied a little too early. Such interventions can annoy the driver but are much less likely to cause a direct injury risk because there was a genuine need for braking, whether human or system applied. With a prototype vehicle that had not yet undergone tuning to eliminate false positive brake applications, 17 false system activations were logged during the road trial where braking would have occurred if the system was fully operational. In seven cases, the system demand would have been limited to a deceleration 4m/s^2 and in the remaining 10 cases it would have peaked at a demand of between $8.0\text{m/s}^2 - 9.8\text{m/s}^2$.

What the brake system would actually have delivered in response to these braking demands depends on the duration for which they were demanded and the initial speed because air brake systems are relatively slow to react and build up compared with hydraulic systems. To estimate this lag, information from the vehicle manufacturer and data from the true positive test programme was used. Firstly, the manufacturer indicated that it would take approximately 0.15 seconds for the AEB demand signal to be delivered to the braking system. In addition, the results from the true positive tests then showed that it would take a further 0.05 seconds before the deceleration began to significantly ramp up (Figure 4).

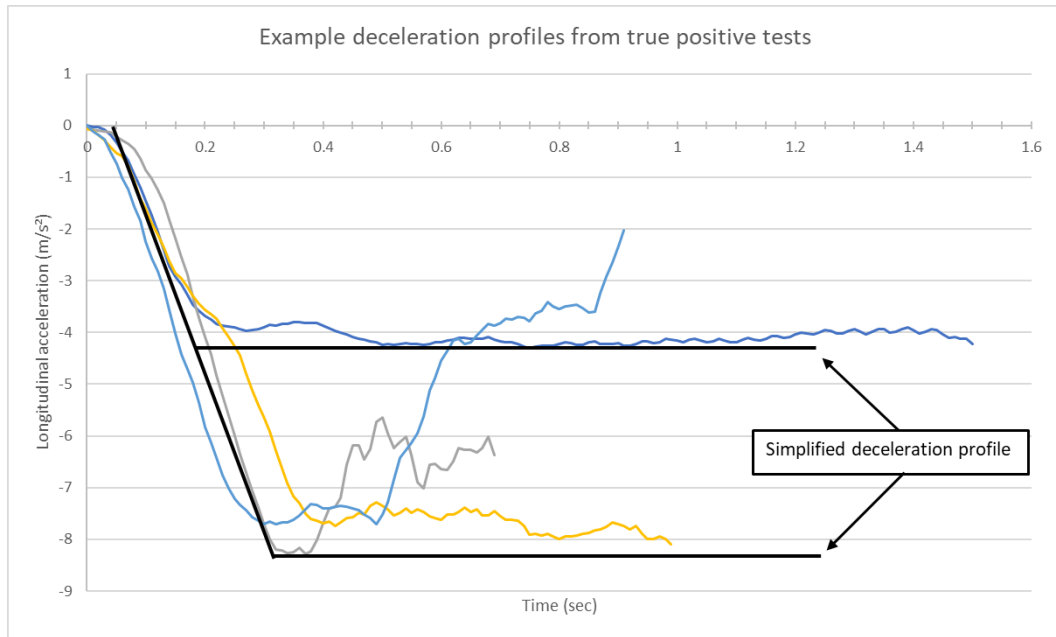


Figure 4: Example deceleration profiles from true positive test

Based on this information, a simplified deceleration profile of the actual level of braking that occurred during each false positive event was calculated, as illustrated by the example in Figure 5.

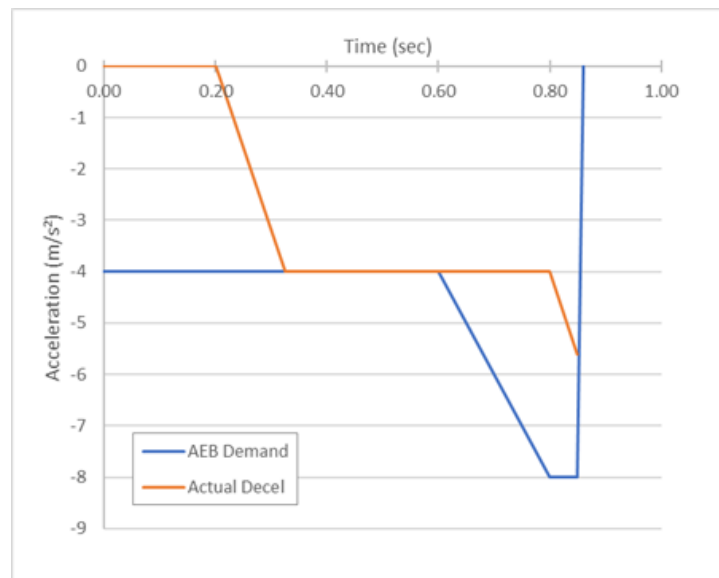


Figure 5: Comparison of braking demand and actual estimated braking

The estimated response of the braking system was applied to the level of deceleration demanded by the system and the actual peak deceleration calculated. Figure 6 shows that in some cases, the actual peak deceleration of the bus was lower than the peak demand, and in four of the 17 false positive events (24%) the duration of the demand would have been too short for there to be any deceleration at all.

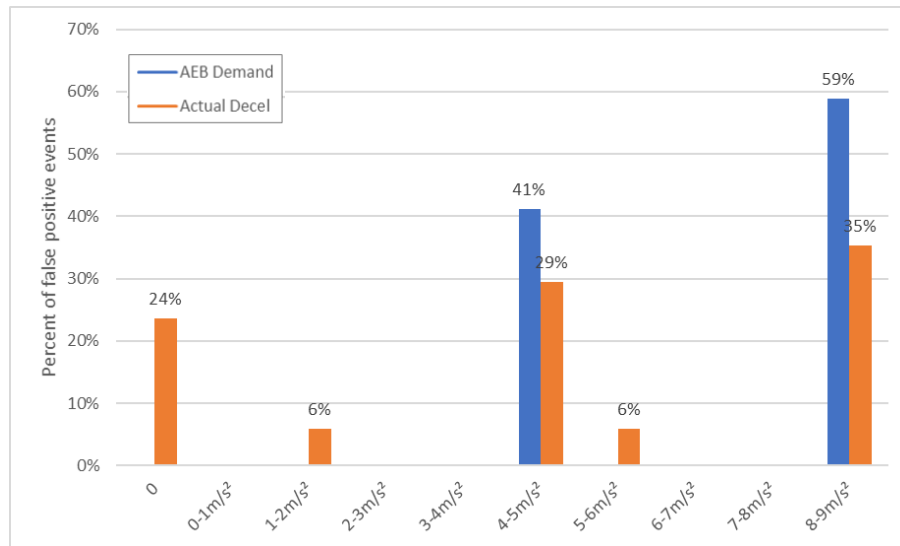


Figure 6: Comparison of AEB demand and actual deceleration for false positive events (road trial)

The false positive events that produced the greatest peak deceleration were all cases in which the level of deceleration ramped up over the duration of the event. Feedback from the manufacturer indicated that this was a result of running the AEB system in an “open loop” mode such that no actual braking took place. For example, Figure 7 shows one event where the AEB system initially demanded a deceleration of 4m/s². The system will check in the next instant and detect that no actual braking had occurred and that the vehicle was now closer to the hazard such that a higher level of deceleration is required to avoid a collision. In reality, a production system would have responded to the initial demand so the ramp up of acceleration may not have occurred or may have been smaller.

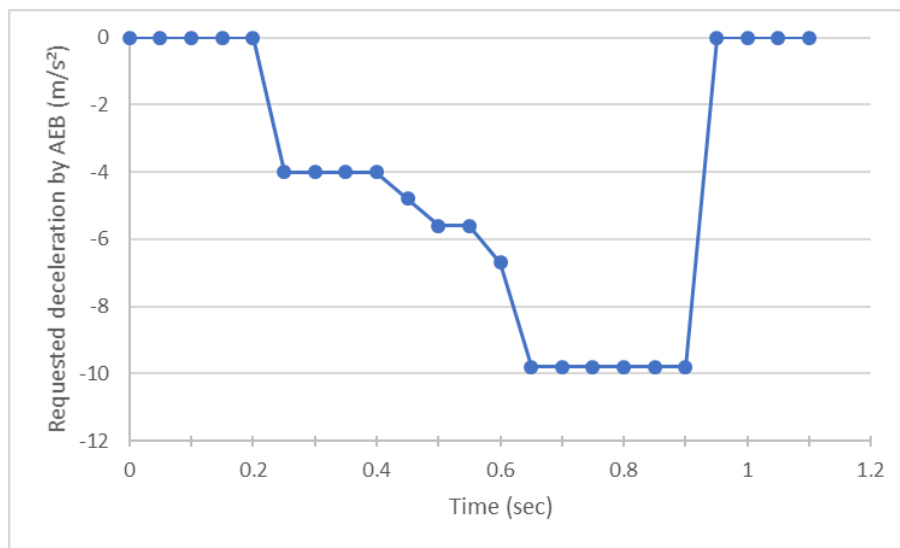


Figure 7: Example of increasing AEB brake demand during open-loop operation

The peak value of deceleration that would have been requested during normal “closed-loop” operation is unknown, but it is reasonable to expect that it would be somewhere between the initial requested deceleration of 4m/s² and the peak deceleration of 7.5m/s² observed during the track tests involving false positive scenarios.

In order to translate information on the deceleration achieved during false positive brake applications to their potential for casualties it was necessary to understand how many falls and injuries occur as a result of braking acceleration more generally. A range of laboratory experimentation has attempted to assess thresholds below which

standing occupants would not fall. For example, (De Graaf & Van Weperen, 1997) found that even very low accelerations ($<1/5 \text{ m/s}^2$) could make a standing occupant fall. They also showed that the rate of change of acceleration (or brake jerk) could be a significant factor in making people fall. The effect of acceleration on the frequency of falls can also be quantified from existing real-world data about buses not equipped with AEB.

The average number of driver-applied brake events per km was recorded during the 400km road trial and divided by peak deceleration. In the relatively short road trial no emergency brake activations were required, so the results were extrapolated to estimate the potential frequency of higher deceleration events (Figure 8). Applying these figures to the total number of bus vehicle km travelled in London each year (490million²) gave an estimate of the number of deceleration events that occur in London each year by peak deceleration.

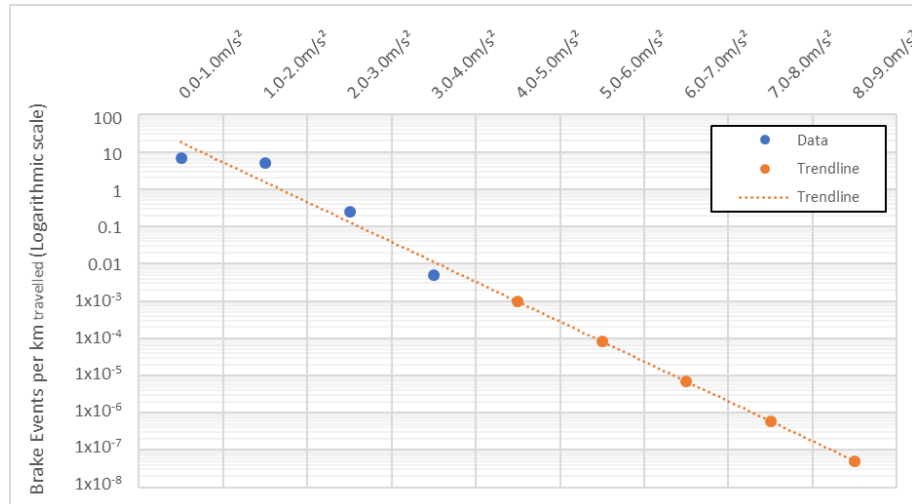


Figure 8: The frequency of brake applications in normal London bus service, by level of peak deceleration.

Data from the CCTV analysis (Figure 9) shows the proportion of casualties that occur at each acceleration level.

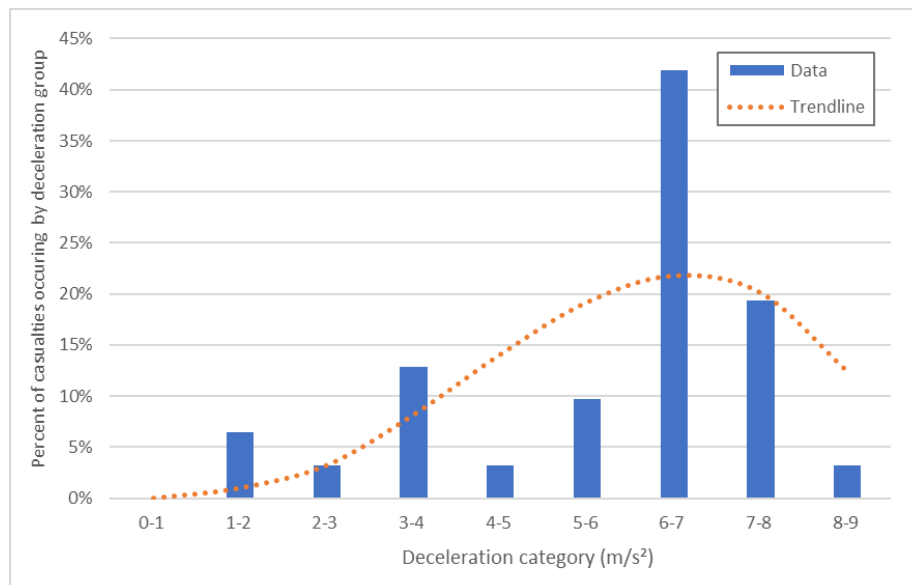


Figure 9: Proportion of bus occupant casualties that fell under braking by peak deceleration.

² Source: DfT Bus Statistics Table BUS0203b. Note TfL data suggests a total of 492.3 million bus km for 2016/17

Analysis of the IRIS database identified an average of 974 casualties per year that resulted from non-collision incidents in which braking was coded as the cause of the injuries. Combining this total with the proportions in Figure 9 produced an estimate of the annual average number of London bus occupant casualties that occur at each braking level. Combining this with the frequency of brake events by deceleration allows an estimate the number of casualties per braking event at each acceleration level. The results are shown in Table 1, below.

Table 1: Estimated number of casualties per braking event by deceleration level

Deceleration (m/s ²)	Brake events/year in london buses (number)	Bus occupant casualties per deceleration event (rate)
0.0-1.0m/s ²	3,277,342,050	0.00
1.0-2.0m/s ²	2,420,568,735	0.000000026
2.0-3.0m/s ²	119,064,478	0.00000026
3.0-4.0m/s ²	2,454,938	0.000051
4.0-5.0m/s ²	468,428	0.000067
5.0-6.0m/s ²	40,020	0.0024
6.0-7.0m/s ²	3,419	0.12
7.0-8.0m/s ²	292	0.65
8.0-9.0m/s ²	25	1.26

This analysis shows that the laboratory experiments on balance and falling cannot be taken to directly map to a probability of falls. It certainly does happen that standing passengers fall at accelerations of 1.5 m/s² as expected by (De Graaf & Van Weperen, 1997). However, in real service with more than 2 billion brake applications in London each year reaching that sort of level, then if a fall was anything but extremely rare in light braking, then the total number of casualties from falls under braking would be huge. The empirical evidence (974) suggests that this is not the case. Based on the CCTV study, the proportion of those at less than 2 m/s² is small. Overall, the probability of injury as a result of that level of acceleration is tiny. The probability of injury rises very sharply at accelerations of around 5 or 6 m/s².

Net effect of true and false positive situations. Given the information above, and knowledge of how many false positives brake applications would be likely to occur in service, it was possible to estimate the total number of bus occupant casualties that would occur as a consequence of false positives. The casualties were divided by severity based upon the observed distribution in bus occupant falls resulting from normal bus driving. However, at this stage of the research, and of the development of the prototype system that has been studied, the eventual false positive rate of a production London bus system is fundamentally unknown. The rate observed during the road trial with the early prototype vehicle is in no way indicative of expectations of the final production version. No published information has been identified that can confirm the typical false positive rate experienced by comparable systems already in production. Thus, results have been expressed in terms of the effect on casualties given different assumptions about the distribution of decelerations in false positive events and different frequencies of events (Figures 10 and 11).

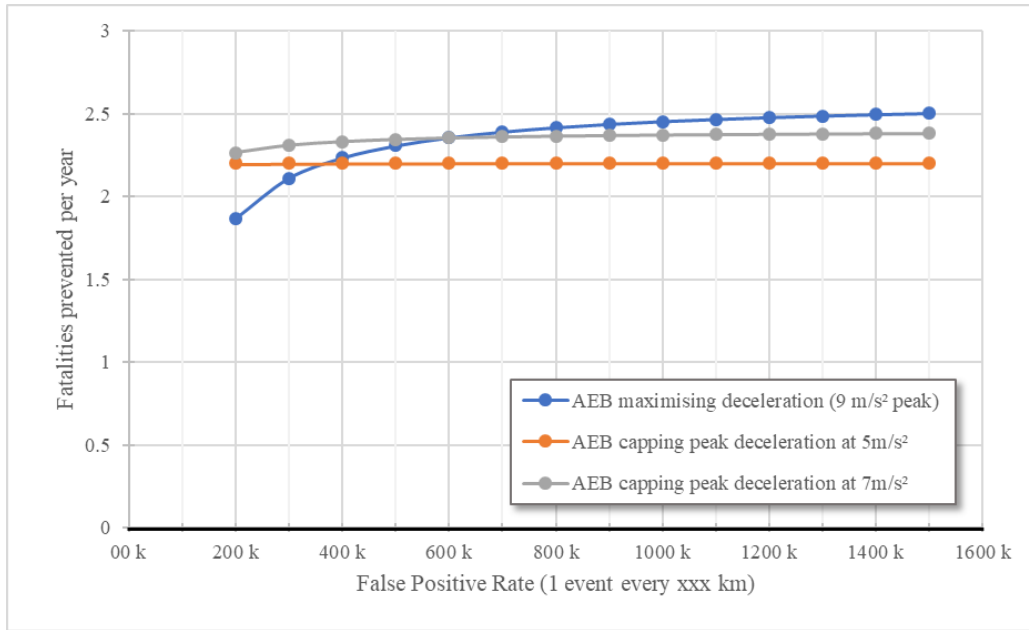


Figure 10: Central prediction of AEB effect on fatalities by false positive rate

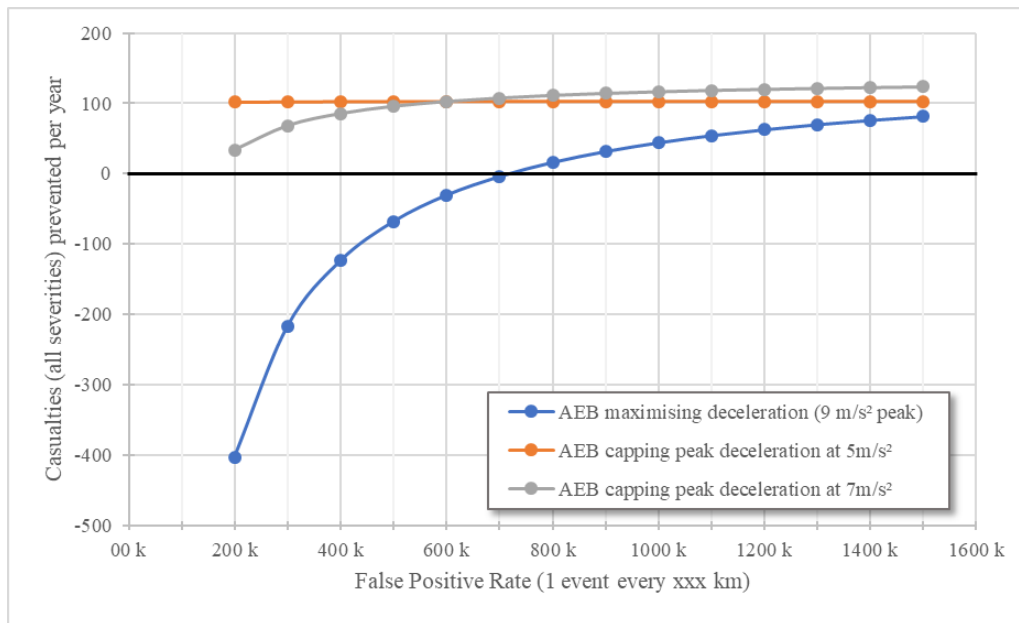


Figure 11: Central prediction of AEB effect on casualties of all severities by interval between false positives

It can be seen that the smaller the distance travelled between false positives, the less the benefit is. At intervals between false positives of greater than 700,000km, all of the AEB braking strategies considered offer a net benefit in terms of the total number of casualties prevented. For fatalities, the most effective system is that with the highest deceleration provided a good false positive rate is achieved. However, this is the least beneficial system if all casualties are considered, because of the effect of false positives on bus occupants falling under braking, which predominantly result in slight injuries. In order to balance these considerations, the casualties were monetised according to standard valuations provided by the UK Department for Transport and the results are as shown in Figure 12, below.

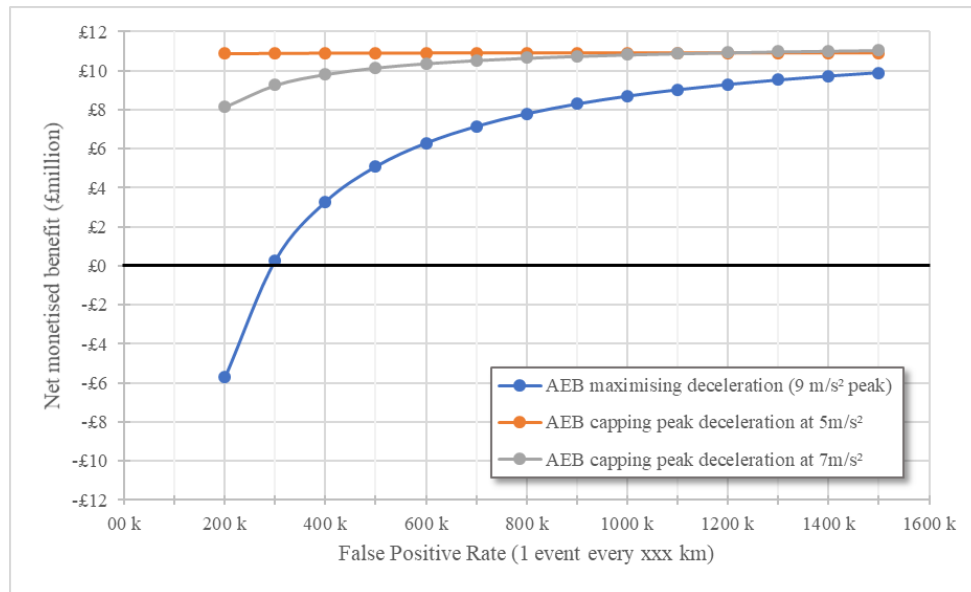


Figure 12: Central prediction of AEB effect on net monetised benefit of casualty prevention, by interval between false positives

Development of test procedures and rating scheme

Test Scenarios. The approach of this project was to base decisions on the inclusion of different test scenarios, and the weighting of each variable within an overall test score, based on the risk to casualties defined using casualty data extracted from the STATS19 database. On this basis, the following test scenarios were selected for inclusion in the Bus AEB test protocol (equivalent EuroNCAP test code shown in brackets):

- Pedestrian crossing.
 - Adult walking from nearside (CPNA-25 & CPNA-75)
 - Adult running from farside (CPFA-50)
 - Child walking from nearside - obstructed by car (CPNC-50)
 - Longitudinal cyclist - 25% and 50% overlap (CBLA-25 & CBLA-50)
- Bus to stationary car (CCRs)

The adult walking from nearside test is to be repeated in night-time conditions because the collision statistics show that performance at night in street lit conditions will be an important feature of an effective system.

Longitudinal pedestrian tests were not included because the collision data highlighted that, over a 10-year period, there were no pedestrian fatalities with a bus when the pedestrian had been walking along in the road. Cyclist crossing tests were also excluded because the prototype vehicle that was used for testing in the project was unable to achieve significant performance in this configuration.

In addition to the above tests, an aborted crossing test was also added to assess the false positive performance of a system. It has the same test geometry as the true positive test that assesses an adult walking from the nearside. However, instead of crossing into the path of the bus, the VRU dummy stops at varying lateral distances from the path of the bus. An effective system will need to activate before the pedestrian enters the path and the scoring is set such that it is acceptable to activate a small distance outside the path but where activations occur while the pedestrian is still at greater distances, the score is penalised to disincentivise this.

A 'bus stop' scenario was also added based on some of the false positives observed during the road trial (Figure 13). For this false positive test, the vehicle follows an s-bend path driving past a stationary pedestrian positioned to the

nearside of the vehicle. At all times in this test the VRU is easily avoidable by steering and, therefore, the AEB should not intervene. Thus, passing this test is considered a pre-requisite that all vehicles must achieve. However, a concern was flagged that the easy way to achieve this would be to switch off AEB whenever steering angle was applied, which would be undesirable. To ensure that this does not happen, a true positive version of this scenario was also included. For the true positive case, test geometry is the same as for the false positive test except that the pedestrian movement is configured such that it is on a collision course with the centre of the front of the bus.

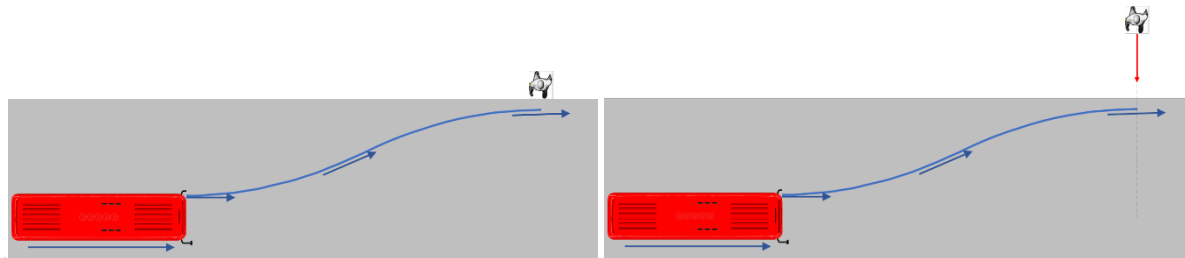


Figure 13: Bus- stop tests. False positive test (left), true positive test (right)

DISCUSSION

Strong potential benefits of fitting AEB to city buses exist in true positive situations, in particular for preventing pedestrian fatalities. Up to around 25% of pedestrian fatalities caused in collision with a bus could be prevented. In addition to this, there are significant benefits in reducing more minor collisions with other vehicles, particularly cars and buses. This will have little effect on fatality statistics but should benefit bus operators in terms of reducing high frequency damage and low severity injury claims, reducing operating costs and downtime.

The risk that AEB causes injury to unrestrained or standing bus occupants in true positive situations exists but is very low due to low numbers of true positive events, potentially earlier brake intervention and only small increases in required decelerations compared to those recorded in driver applied situations.

The risk to bus occupants as a consequence of falls during false positive events is substantial and a good false positive rate is very important to minimise this risk. The level of deceleration applied in false positive events will also be very important.

Permitting an AEB system that maximises the braking performance of the bus (AEBmax) has the potential to save the most fatalities, provided that false activations occur less than once every 600,000 vehicle-km on average. However, capping peak deceleration to a maximum of 7 m/s^2 has the potential for the largest reduction in monetised casualty benefit. This is because the analysis shows that the reduced deceleration substantially reduces the risk of large numbers of slight injuries to bus occupants as a consequence of false positive activation while reducing the monetised benefits to fatalities by less.

However, this analysis will only hold true if the correlation between the risk of injuries to standing and seated but unrestrained occupants is with peak deceleration only. Experimental data suggests that the rate of change of deceleration (brake jerk) is also an important factor in the risk of injury. The empirical analysis could not account for that factor and with a capped deceleration there would be an incentive to increase the brake jerk to improve true positive performance. Thus, there is a risk capping deceleration could fail to achieve the benefits expected by the analysis or even reverse them.

The analysis of benefits versus disbenefits is also very strongly dependent on two key input parameters that are weakly based (due to small sample sizes): the frequency with which heavy brake applications (5 m/s^2 +) occur in real service and the frequency with which bus occupant casualties occur under different levels of braking acceleration. This is particularly true when considering an AEB system that can apply peak braking of 9 m/s^2 . Further research is proposed to increase the sample size available for these elements with a view to increasing confidence in the results.

Requirements have been developed for AEB that effectively define a minimum standard that must be achieved in terms of true and false positive performance to be considered an AEB system suitable for a London bus. In addition to this, the tests then measure and rate additional performance in excess of this standard. Thus, if implemented in an appropriate purchasing specification in this form, the market would be free to choose how to implement AEB in terms of deceleration levels, brake jerk etc.

The test track assessments developed are based on the Euro NCAP tests for cars, with adaptations to account for different collision patterns observed with London buses. The assessments contain two novel false positive tests because of the degree to which false positive rate is considered critical to the net benefit of the system. However, the track test assessments merely ensure to the extent possible that the systems are well designed and will work in the real world. There are an almost infinite range of circumstances that can be encountered in the real world and not all can be tested on a test track. It is, therefore, very important that industry design for real world use and not just test track performance. This is of particular concern in relation to false activations. The inclusion in any resulting specification of a requirement for industry to demonstrate to TfL how they have satisfied themselves that they will achieve a defined false positive rate in the real world, would add additional reassurance of proper design diligence.

CONCLUSIONS

AEB on city buses offers clear potential benefits in true positive situations, particularly in collisions involving pedestrians, preventing up to around 25% of pedestrian fatalities based on the analytical modelling presented in this paper.

False positive activations clearly risk significant increases in typically lower severity injuries to bus occupants who are standing or seated but unrestrained. The frequency with which false positives occur, and the deceleration achieved in false positive events will be critical to the success of any implementation.

Analysis suggests that if, in service in a busy city, the average interval between false positives is more than 600,000km, then substantial net benefits would be achieved.

The analysis is particularly sensitive to two results derived from small sample sizes and additional research is planned to improve the robustness of the data.

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